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Using Photovoltaic (PV) Cells on Enduring DoD Installations in the Middle East: A Feasibility Study

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June 2013

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The focus of this research is to ascertain the feasibility of the use of solar energy on enduring Department of Defense (DoD) installations located throughout the Middle East. DoD installations are currently using electricity generated either from the local grids at commercial rates, or contractor-provided diesel generators. Growing commercial use of solar energy demands proper analysis for its viability on use at DoD facilities.

This paper will analyze available solar technology, its cost effectiveness in the military environment, power requirements of DoD installations, and economies of scale based on power consumption. We will provide a brief summary of the latest research in the field of solar energy, including current status, future prospects and issues related with the use of solar energy, and ways to resolve these issues especially with regard to availability, cost, and sustainability.

A look at future plans for the use of renewable alternate energy sources within the DoD shall give us some guidelines with respect to their effect on power requirements vis-à-vis future cost structure. Based on the results of the research some statistical analysis may be carried out. The outcome of our analysis shall be translated into recommendations for DoD leadership for future planning and acquisition activities.

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USING PHOTOVOLTAIC (PV) CELLS ON ENDURING DoD INSTALLATIONS IN THE MIDDLE EAST: A FEASIBILITY STUDY

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LIST OF ACRONYMS AND ABBREVIATIONS

DoD	Department of Defense
DOE	Department of Energy
DPGDS	Deployable Power Generation and Distribution Systems
EMD	Electro Motive Division
LCC	Life Cycle Cost
LCOE	Levelized Cost of Electricity
LSA	Living Support Area
NREL	National Renewable Energy Laboratories
TOC	Total Ownership Cost
TQC	Tactical Quiet Generators
GW	Gigawatt
FOB	Forward Operating Base
SERDP	Strategic Environmental Research and Development Program
DARPA	Defense Advanced Research Projects Agency
WACC	Weighted Average Cost of Capital

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EXECUTIVE SUMMARY

DoD is the world's largest institutional energy user. One of the challenges faced by the DoD is seeking solutions to lessen our nation's dependence on imported oil through energy efficiencies, renewable sources and advanced biofuels. Dedication of all concerned to achieve this goal has placed the DoD in a prominent leadership position. Military installations are adopting clean energy technologies and improving energy efficiency that save taxpayer dollars.

The global total of solar PV installed capacity was roughly 67 GW at the end of 2011, to be compared with just 1.5 GW in 2000. Over the past five years, solar PV has averaged an annual growth rate of over 50%. The emergence of the solar PV sector as a clean energy source presents DoD with opportunities for saving money in the years ahead. We have analyzed a trend in levelized cost of electricity (LCOE) for solar PV and have come to conclusion that solar PV will become competitive with grid energy around 2020 provided current growth projections in installed capacity and corresponding decrease in cost of solar PV generated electricity continues.

In light of our finding, we are confident that solar PV has potential to compete with grid electricity any time in near future. This will not only result in cost savings but also social benefit to society due less pollution during generation process. We, therefore, recommend that the Strategic Environmental Research and Development Program already involved in addressing the sustainability issues at FOB carry out a complete cost benefit analysis prior the making strategic decision to shift to solar energy.

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I. INTRODUCTION

A. BACKGROUND

The Energy Policy Act of 2005 was signed into law by then President George W. Bush on August 8, 2005. Section 203 *Federal Purchase Requirements* requires that the federal government offset its electric energy consumption with an increasing percentage of “renewable energy” from 3 percent starting in 2005 to not less than 7.5 percent by 2013 and each fiscal year thereafter (Andrews, 2009).

The Department of Defense (DoD) accounts for approximately 63 percent of the energy consumed by federal facilities and buildings (Andrews, 2009). The DoD is the single largest consumer of energy in the U.S., and its energy costs during fiscal year 2011 totaled U.S. $20 Billion (Eidsen, 2012). Secretary of the Air Force Michael Donley presented a keynote address on the Department’s energy initiatives at the 2012 National Clean Energy Summit in Las Vegas on August 7, 2012. To highlight the top leadership’s priorities regarding energy consumption and future expansion capabilities, the Secretary stressed the need to provide the correct tools and resources for successful operations. A critical component of the correct tools and resources is having assured access to reliable supplies of energy. “Energy is a critical part of everything we do in the Air Force and across DoD, . . . Reducing energy demand and increasing energy supply sources are vital areas as the department looks to identify efficiencies and expand capabilities” (Donley, 2012).

The DoD continues to make progress installing cost-effective renewable energy technologies and purchasing electricity generated from renewable sources (solar, wind, geothermal, and biomass). In FY 2009, 3.6 percent of the DoD’s electrical consumption came from renewable electricity sources, exceeding the EP Act 2005 goal of 3 percent and improving on the 2.9 percent achieved in FY 2008 (DoD, 2011).

One of the challenges faced by the DoD is seeking solutions to lessen our nation’s dependence on imported oil through energy efficiencies, renewable sources, and advanced biofuels. Dedication of all concerned to achieve this goal has placed the DoD in a prominent leadership position. Military installations are adopting clean energy technologies and improving energy efficiency that save taxpayer dollars. (Reichart, 2011)

Throughout its history, the U.S. DoD has invested in new ways of harnessing energy to enhance the strength, speed, range, and power of the Armed Forces. Until recently, the U.S. military's innovation agenda has not placed a high premium on energy efficiency and new sources of energy and fuels. But the Department's experience conducting wars in Iraq and Afghanistan and the rise of new global threats and challenges have caused the DoD to rethink its strategic energy posture. Special emphasis has been placed on reducing battlefield fuel demand and securing reliable, renewable energy supplies for combat and installation operations (Reichart, 2011).

The DoD has completed a full withdrawal of U.S. forces in Iraq, and plans to transition from Afghanistan in 2014. However, enduring locations throughout the Middle East and beyond will remain in support of the United States' commitment to the Global War on Terrorism. U.S. activities will not be limited to DoD operations but also Department of State missions in various locations throughout the region including the largest U.S. Embassy in the world located in Baghdad, Iraq. Bases located in Kuwait, Bahrain, Qatar, and the Horn of Africa, are to remain indefinitely. These facilities all use fossil fuels to carry out day-to-day operations. With the DoD aiming to become less dependent on foreign oil sources—for strategic and economic reasons—we have a need to study the current and future feasibility of utilizing PV cells as a source of energy. Though regions such as the Middle East are attractive areas to study the feasibility of solar energy due to their climate, this study will not limit itself to one area. Solar technology has advanced a long way and proven itself to be a promising technology. Commercial use of solar panels to generate electricity has already been in place. Use of solar panels as an alternative source of electricity has environmental benefits. Efficiency and cost effectiveness has been a barrier for wide commercial use of solar energy. Extensive research in the field is bringing improvements in solar generation systems with every passing day. Technology has sufficiently matured to allow for a detailed economic study of the economies of scale. This paper will look at the current conditions of solar energy with respect to the world market and focus on the cost effectiveness of future implementation.

B. LEGISLATION

As mentioned earlier, the DoD consumes about 63 percent of all energy used at federal government facilities (Andrews 2009). Initiatives aimed at reducing energy consumption can be traced back to 1973. This list includes:

1. The 1973 Federal Energy Management Program (FEMP)
2. The 1978 National Energy Conservation Policy Act (NECPA), which required federal agencies, including DoD, to report annually on the energy consumption by their buildings, operations, and vehicles. Overall federal energy consumption is reported annually to Congress by the Department of Energy (DOE) Federal Energy Management Program (FEMP).
3. The 1985 Deficit Reduction Act
4. The 1992 Energy Policy Act
5. The Energy Policy Act of 2005 (EPACT – P.L. 109–58)

   Section 203. *Federal Purchase Requirement* requires that the federal government offset its electric energy consumption with an increasing percentage of "renewable energy" from 3 percent starting in 2005 to not less than 7.5 percent by 2013 and each fiscal year thereafter.

6. The Energy Independence and Security Act (EISA) 2007 (P.L 110–140)

   Section 431. *Energy Reduction Goals for Federal Buildings* amends the National Energy Conservation Policy Act (NECPA) by mandating a 30 percent energy reduction in federal buildings by 2015 relative to a 2005 baseline.

7. NATIONAL DEFENSE AUTHORIZATION ACT FY 2007 (P.L 109–364)

   Section 2852. *Department of Defense Goal Regarding Use of Renewable Energy to Meet Electricity Needs* amends 10 U.S.C. 2911 by making it DoD's goal to produce or procure at least 25 percent of its electric energy consumption from renewable sources by the year 2025.

8. NATIONAL DEFENSE AUTHORIZATION ACT FY 2008 (P.L 110–181)

Section 828. *Multiyear Contract Authority For Electricity From Renewable Energy Sources* authorizes contracts periods of up to 10 years for purchasing electricity from sources of renewable energy.

9. Executive Order 13423 (the 2007 Executive Order)

   Executive Order 13423 directs that an amount equal to half of the statutorily required renewable energy be generated by sources placed into service in 1999 or later

B. PROBLEM STATEMENT

The DoD maintains a substantial number of enduring installations in the Middle East and central Asia in countries such as Kuwait, Qatar, Bahrain, and Afghanistan. The Department of State also maintains facilities across the region such as the largest overseas U.S. Embassy located in Baghdad, Iraq. The requirements of electricity for these facilities are met mostly by contractor-operated diesel generators or electricity purchased from the local power grid that is not always reliable (Murphy & Sebti, 2005). As an alternative, effective use of solar energy may result in considerable savings and operational efficiency.

The emergence of the clean energy sector and increasingly competitive alternative energy sources presents DoD with opportunities for saving money in the years ahead. Therefore, this paper will seek to address whether the use of solar energy would be cost - effective in these locations.

Fixed installations that provide critical support to combat forces can be reliably powered by micro grids, “smart” technologies, and renewable energy sources. Energy efficiency and renewable energy will help the department avoid price shocks that have come to characterize world oil markets. In contrast to oil prices, the cost of renewable energy has been declining rapidly in recent years. The cost of solar panels, for example, has decreased by more than 60 percent since 2009 (Reichart, 2011).

The aim of this paper will, therefore, be to carry out an analysis of the use of solar energy panels at DoD installations with respect to its cost-effectiveness in installation, operation, maintenance, mobilization, security, sustainability, logistical support, and reliability.

C. METHODOLOGY

We will use available literature and meteorological data which gives the average monthly sunlight levels for different geographical areas, effectiveness of the commercial solar PV panels currently available and electricity consumption levels for different times of the day and current cost structures. Non-economic attributes of solar installations need to be considered along with economic benefits in order to assess the feasibility of solar power as a substitute for the current electric utility.

Relevant data for this paper is collected from scholarly literature in relevant fields, renowned solar companies, meteorological data, relevant standards, official records, and through correspondence with the DoD commands and commercial contacts. Data may also be collected using email, correspondence with key personnel identified by the researchers and from existing online databases.

D. SCOPE AND OBJECTIVE

Renewable energy is defined as electrical energy generated from solar, wind, biomass, landfill gas, ocean (including tidal, wave, current, and thermal), geothermal, municipal solid waste, or new hydroelectric generation capacity achieved from increased efficiency or additions of new capacity at an existing hydroelectric project (DOE, 2010). For the purpose of this paper, we only consider solar energy.

In the years ahead, the emergence of the clean energy sector presents DoD with opportunities for saving lives and money. Clean energy initiatives will reduce fuel demand and operational risk. PV solar cells can be produced locally to enhance the security of energy supplies. New energy technologies also help strategically protect the Department.

In recent decades, DoD technology development efforts have supported commercial development of computers, the Internet, the Global Positioning System, semiconductors and many other innovations. DoD has a broad range of strengths that can help accelerate clean energy technology development and commercial maturity. These include an established research and development infrastructure, ability to grow demonstration projects to scale, significant purchasing power and the necessary culture and management infrastructure necessary to foster innovation. Historically, DoD has extensive experience in converting an innovative idea into reality. The well-matured acquisition system is capable of transforming an idea to a mature technology. Although DoD was the first beneficiary of that technology, it was later that commercial applications of the technology benefitted the community as a whole and has supported economic growth as well.

As the world's largest institutional energy user and with a broad range of facilities, DoD is an important player in the development and deployment of renewable energy technologies. In fiscal year 2010, the Department produced or procured 9.6 percent of its electric energy consumption from renewable energy sources, minimal short of the National Defense Authorization Act goal of 10 percent (Reichart, 2011).

At the research level, DARPA has led a concerted effort to develop solar cells that achieve 50 percent conversion efficiency, more than twice the current rate of leading technologies. Conversion efficiency is the ratio between the useful output of an energy conversion machine and the input, in energy terms. Record conversion efficiencies of greater than 40 percent have been achieved, and the public-private partnership is exploring next steps in product engineering and manufacturing (Reichart, 2011).

As of mid-2010, the Department of Defense was operating more than 450 projects involving solar, wind, geothermal and biomass energy. The U.S. Navy accounts for 60 percent of DoD's renewable energy projects—some 250 in total. The 14-megawatt solar array at Nellis Air Force base in Nevada is one of the largest projects in the United States, although large-scale projects in the 250 to 1,000 MW range are in development (Reichart, 2011).

These examples show that the use of solar energy in DoD installations more than a dream—it is becoming a reality. There are certain issues with the conversion efficiency of PV solar panels. As already highlighted, much of the research work has already been carried out and the target of 50 percent conversion efficiency does not seem unattainable. Resources like experienced work force, innovative culture with will to succeed makes DoD an ideal organization to achieve this target of 50 percent efficiency.

We initially limited our research to the Middle East area based on the data available. However, all the analysis can be duplicated for any other region of the world based on the meteorological data regarding average available Sun hours and the associated conversion efficiencies along with using the Levelized Cost of Electricity.

E. ASSUMPTIONS AND LIMITATIONS

We made the following assumptions to reach our findings:

1. Current growth rate of solar PV electricity continues.
2. Cost reduction trend in solar PV generated electricity continues for next 7 years.
3. The U.S. dollar will maintain its parity in international market.
4. PV power generation will continue increasing in efficiency and decreasing in price.
5. PV power generation will be employed in future in many commercial applications.
6. We limited our research to evaluate feasibility of using PV cells for electricity generation in basic forward operating bases.

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II. LITRATURE REVIEW

This paper began with a literature review of PV solar technology, conversion efficiencies, technology improvements over time associated installation and operation costs and issues with PV Solar technology. Energy development is increasingly dominated by major global concerns of over-population, air pollution and fresh water pollution. Production of clean energy sustainability presents a challenge due to large-scale energy-related activities at the global level. (Lior, 2007). PV solar energy is a solution to all these concerns.

A. HOW PV SOLAR CELL WORKS

The solar cells are also called photovoltaic (PV) cells, which convert sunlight directly into electricity. A module is a group of cells connected electrically and packaged into a frame known as a solar panel. These solar panels can then be grouped into larger solar arrays, like the one operating at Nellis Air Force Base in Nevada.

PV cells are made of semiconductors such as silicon—currently the most commonly used. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely. PV cells have one or more electric fields that act to force electrons freed by light absorption to flow in a certain direction. Current caused by the flow of these electrons can be collected by placing metal contacts on the top and bottom of the PV cell. This resultant current, together with the cell's voltage, defines the power (or wattage) that the solar cell generates. The basic formula for calculating the power output is given by P (power) = V (voltage or electric field) * I (amount of resultant current) (Toothman & Aldous, 2000).

B. TECHNOLGICAL ADVANCES

Since the introduction of EPA 2005, the interest in solar energy has rapidly increased. Solar energy components continue to improve in efficiency and decline in price; the U.S. Department of Energy forecasts that solar energy will start to reach cost parity with retail electric costs by 2016 (Toothman & Aldous, 2000).

Historically, it has been believed that use of solar energy is an alternative (or supplement) to utility power. This traditionally held notion is no longer true, as solar energy is becoming a symbol of energy self-sufficiency and environmental sustainability. The growth in solar installations can be attributed more to the non-economic benefits than as an economic substitute for electric utility. Households and businesses wanting to reduce their carbon footprint see solar energy as a strong complement to energy efficiency. Volatility in natural gas prices makes free solar fuel look even more attractive as a price hedge (Ross, 2013).

The idea of acquiring free electricity from the Sun has been around for decades. This idea has already been proven scientifically viable, and PV Solar panels are being used around the globe for electricity generation; however, there is still a wide range of improvement. On any bright, Sunny day, the Sun's rays give off approximately 1,000 watts of energy per square meter of the planet's surface. We have not been able to tap all of this energy, and if we could collect all of that energy, the dream of "solar revolution" can come true (Toothman & Aldous, 2000).

The idea of using sunlight to produce an electric current in a solid material was conceived in 1839. Science has come a long way in truly understanding this process. PV effect caused certain materials to convert light energy to electrical energy at the atomic level. After one-and-a-half-centuries, the benefits of PV solar energy are now being realized. (DOE, 2013)

The United States Government and the Department of Energy (DoE) enhanced their involvement in the PV development with the establishment of National Renewable Energy Laboratories (NREL) in 1977. The turn of the century has brought continued PV technology growth with PV solar-powered planes developed by NASA and larger systems producing more PV solar power (DOE, 2013).

C. CURRENT PV CELLS MARKET

As per IEA statistics, renewables accounted for 19.5 percent of global electricity generation in 2009. The global total of solar PV was roughly 67 Gigawatts (GW) at the end of 2011, to be compared with just 1.5 GW in 2000. Over the past five years, solar PV has averaged an annual growth rate of over 50 percent. Germany and Italy accounted for over half the global cumulative capacity, followed by Japan, Spain, the United States and China. As compared to PV solar energy, global wind power capacity was 238 GW at the end of 2011, up from just 18 GW at the end of 2000, with an average growth rate of over 25 percent over the past five years. Although current total electricity generation from wind power is greater than the total electricity generation by PV solar panels, still average growth rate of PV Solar is much higher. (DOE, 2011)

The major question is the PV energy competitiveness and sustainability of solar energy as a standalone power source. The renewable energy sector is demonstrating its capacity to deliver cost reductions, provided that appropriate policy frameworks are in place and enacted. Deployment is expanding rapidly. Costs have been decreasing and a portfolio of solar energy technologies is becoming cost-competitive in an increasingly broad range of circumstances (IEA, 2013).

The major issue with solar energy is its dependence on weather and the availability of sunlight for conversion to electricity. Research and Development work for development of efficient and cost effective energy storage systems has already commenced. The basic concept is to use high performance batteries on the bases of lithium ion to store energy until the time of consumption. At Karlsruhe Institute of Technology (KIT), several pilot plants of solar cells, small wind power plants, lithium-ion batteries, and power electronics are under construction to demonstrate how load peaks in the grid can be balanced and what regenerative power supply by an isolated network may look like in the future. These batteries can even cater to the higher loads during peak hours and make sense from economic point of view. Apart from the battery, the key component of the stationary energy storage system is an adapted power electronics unit for charging and discharging the battery within two hours only. Hence, the stationary storage system can be applied as an interim storage system for peak load balancing. During times of weak loads, solar energy and wind electricity are fed into the battery. At times of peak load, the energy from photovoltaic systems, wind generators, and batteries is fed into the grid. Batteries can add a lot of cost and maintenance to a PV system, but it is currently a necessity if you want to be completely independent. (Helmholtz, 2012)

Current PV solar market is concentrated around green power for retail locations, multi-tenant residential environments, and green power for office buildings. With direct savings on utility costs, tax incentives, and increased rentals, green energy becomes the obvious choice.

D. FUTURE TRENDS IN PV CELLS

1. Installation Costs

Installation cost is one of the major considerations for making a final decision regarding use of any type of electricity generation system. While sunlight is free, the electricity generated by PV solar systems is not free. There are many other factors involved which need to be considered in determining whether installing a PV system is cost effective or not. The very first factor involved is the location where we want to install the solar system. Sunny parts of the world start out with a greater advantage than those settled in less Sun-drenched locations, since their PV systems are generally able to generate more electricity. The average unit cost of electricity in the area is another factor.

As of 2009, a residential solar panel setup averaged somewhere between $8 and $10 per watt to install (DOE, 2009). The larger the system, the less it typically costs per watt. PSB offered a final rate of $0.240 per kWh in 2010 for a contract term of 25 years. (Letendre & Soto, 2012) In order to calculate the installation costs realistically, we shall take into account the incentive offered by the government in the form of federal and state tax incentives, utility company rebates, and other financing opportunities.

Currently, solar power still has some difficulty competing with the utilities, but costs are coming down as research improves the technology. Advocates are confident that one day PV will be cost effective in urban areas, as well as remote ones. Part of the problem is that costs can be brought down by manufacturing at large scale, which in turn is feasible if demand exists in the open market. That kind of demand for PV, however, will not exist until prices fall to competitive levels. With increasing awareness of environmental concerns, demand of PV solar cells and efficiencies are rising constantly and as a result prices are going down (Toothman & Aldous, 2000).

2. Operating Costs

Theoretically, the direct conversion of sunlight to electricity without any moving parts or environmental emissions during operation, does not involve any operating costs associated with electricity generated by PV cells; however, this is not completely true.

PV cell electricity costs are normally calculated by three metrics, namely: the price-per-watt (peak) capital cost of PV modules (typically expressed as $1/W); the Levelized Cost of Electricity (LCOE) and the concept of grid parity. Each of these metrics can be calculated in a number of ways, and depend on a wide range of assumptions that span technical, economic, commercial, and policy considerations. Importantly, the usefulness of these three metrics varies dramatically according to audience and purpose. As an example, the price-per-watt metric has the virtue of simplicity and availability of data, but has the disadvantage that module costs do not translate automatically into fully-installed system costs. Different technologies have different relationships between average and peak daily yields, and present the question of whether costs quoted are underlying manufacturer costs versus wholesale costs, or retail prices. LCOE and grid parity are of special relevance to government stakeholders, but require a wider set of assumptions. They vary widely based on geography and on the financial return requirements of investors, and do not allow for robust single-point estimates. Instead, sensitivities are normally required—yet rarely presented—as are explicit descriptions of system boundaries. The financial case for PV depends on the financing arrangements and terms available, as well as estimates of likely electricity prices over the system lifetime. Often the distinction between wholesale and retail prices are not clearly made (M. Baziliana et al., 2012).

The basic incentive to bring all these factors early in the discussion was to highlight various concepts in PV cost calculations. In future discussions, we will dig deeper into these concepts.

III. METHODOLOGY

A. OVERVIEW

Services all over the world are increasingly facing budget cuts due to prevailing uncertain economic conditions. Governments in general and forces in particular, are forced to find ways and means to reduce their costs of carrying daily operations, while increasing efficiency. Technological advancements are also focused to achieve higher efficiencies and cost cuttings.

Energy resource management, especially electricity generation, is a common concern among nations due to the depleting supplies of fossil fuels. DoD is the biggest electricity consumer of the U.S. government. Therefore, DoD is committed to decreasing electricity costs for facilities within the U.S., as well as on overseas installations by designing efficient buildings, installing energy efficient equipment, improving insulation techniques, and effective management of facilities (Acore, 2012).

Our research started with the collection of data. Exact numbers with regard to installation costs of electricity, transportations costs, maintenance cost, operating costs, and disposal costs at DoD enduring installations, were not readily available from open sources. Because of security reasons, we preferred to limit this discussion to data available from open sources.

1. Research Model

There are several cost calculation models available commercially as well as free for analysis. These models are tools to assist management in make or buy decisions. No model is absolute and so robust as to fit every situation. Moreover, each model is based on various assumptions which may be true in one case but may not be applicable to other situations. These models are normally in the form of Excel spreadsheets with several designed inputs and outputs. Outputs may be in the form of numbers, graphs or histograms for comparison of all available alternatives.

The ultimate objective of all models is to calculate total costs for each alternative based on location, market conditions, labor and manufacturing costs, applicable taxes, technology maturity, any relevant government incentive corresponding to a particular alternative, cost of capital, prevailing inflation rates, payment structure and a range of other factors. The model we initially came up with for calculation of total costs of electricity generation by utilizing PV cells and diesel generators is appended in Figure 1.

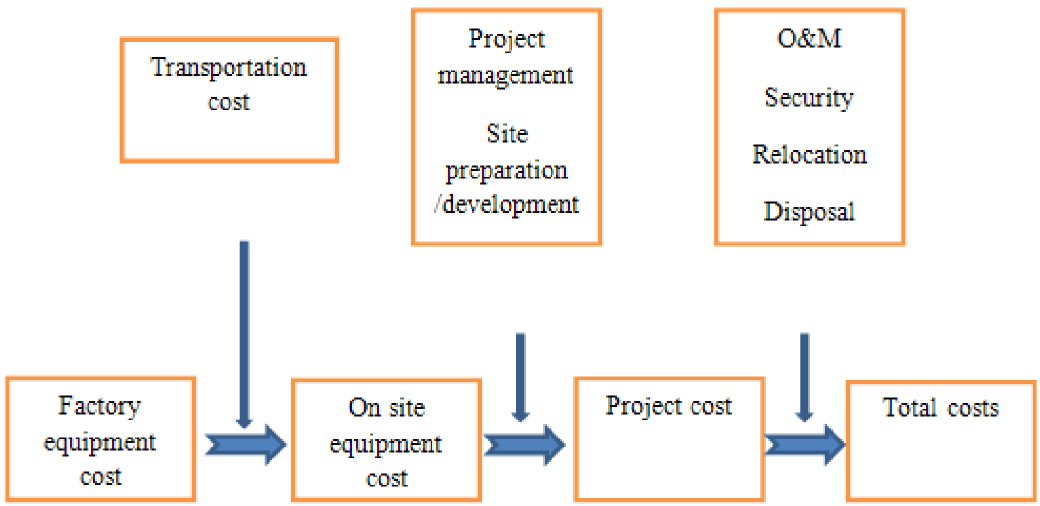

Figure 1. Total Cost Calculation Model

2. Data Collection

Collection of required data from open sources was very challenging. We intended to collect cost-of-electricity data in the same units, and prepared under the same set of assumptions, for both alternatives (diesel and solar). It is an absolute requirement for any useful analysis to maintain the same units. Moreover, all factors depicted in our model were relevant to both private entrepreneurs, as well as DoD, and should have been considered in our cost calculations.

The following three possible data collection approaches were used:

1. Calculate Life Cycle Cost (LCC) – LCC refers to all direct and indirect costs related to building, operating, maintaining and properly disposing of a project over a defined period of time.
2. Calculate Total Ownership Cost (TOC) – TOC refers to sum of all costs associated with the research, development, procurement, personnel, training, operation, logistical support and disposal of an individual asset (USCG, 2002). TOC is a broader term and contain LCC as a sub cost component.
3. Levelized Cost of Energy (LCOE) – LCOE is the constant unit cost (per kWh or MWh) of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life.

We initially focused on the first two approaches. Both concepts are very common in DoD, and usually contain the following cost components:

1. Planning
2. Research and development
3. Acquisition and procurement
4. Training and fielding
5. Operation and maintenance
6. Management and infrastructure costs
7. Modification / up gradation
8. Disposal

Total ownership cost (TOC), or total cost of ownership, is sometimes used or misinterpreted as Life Cycle Cost (LCC). As already highlighted, TOC is the sum of all costs associated with the research, development, procurement, personnel, training, operation, logistical support, and disposal of an individual asset (USCG, 2002). LCC is actually a subset of TOC and mainly focuses on direct and indirect costs related to the program only. Infrastructure costs and management costs are not normally included in LCC.

We selected Camp Buehring in Kuwait as a pilot case study. The major reason for selecting this particular site is due to its electricity utilization in the past and foreseeable future. Camp Buehring has been extensively used since Operation Iraqi Freedom and is expected to remain manned for years to come. The purpose was to calculate total load (electricity consumption) at the camp and all relevant costs separately. We intended to add them up to calculate TOC.

We started with load calculation. The major electricity consuming items are installed in the following facilities:

1. Main Living Space Area with 100 Containerized Housing Units (CHU)
2. Large Utility tents for maintenance and training
3. Office Trailers
4. Twelve men capacity transient tents
5. Large dining facility (DFAC)

Google Earth provides an accurate measuring tool that can be used to calculate the square footage of these structures to a reasonable degree of accuracy. The CHUs have an area of 480-square feet. We have estimated the height of each CHU as 8-feet-tall from a picture downloaded from the Internet and our general experience living in the AOR. We have used these basic building blocks to calculate our load.

3. Load Calculation

We attempted to calculate the electrical load as realistic as possible because our analysis will build upon the load costs comparison for each unit of electricity using PV cells or Diesel Generators (DG). We accounted for for HVAC, lighting requirements, freezing requirements for food supplies, laundry, water pumping/circulation, personal equipment, 24/7 office machinery and aircraft support equipment.

Each CHU has area of 480 square feet. Most of these types of CHUs are split in half to use a more efficient A/C system, and for privacy of the residents. The Department of Energy recommends 20 BTUs for each square foot of space (DOE, 2012) . Two Hundred and Forty square feet would require a 4,800 BTU per hour A/Cs for each CHU. There are 100 CHUs in this Living Support Area (LSA) so the requirement would be 200 x 4,800 BTU per hour A/Cs. The total cooling capacity required to cool all 100 CHUs comes out to be 960,000 BTUs per hour.

Energy load E in kilowatt-hour (kWh) is equal to the power P in watts (W), multiplied by the time period (t) in hours (hr) divided by 1000:

$$E(kWh) = P(W) \times t(hr) / 1000$$

so

$$\text{kilowatt-hour} = \text{watt} \times \text{hour} / 1000$$

or

$$kWh = W \times hr / 1000$$

Each CHU houses 16 tube lights (8 in each subunit). Assuming that all tube lights are 32 watts and remain on 18 hours/day, then each CHU has a power consumption of 9.216 kWh. The total lighting requirements for 100 CHUs becomes 921.6 kWh.

There are 58 Twelve Men Transient Tents (18ft wide x 30ft long) consuming 10,800 BTUs (18 x 30 x 240). There are 326 Big Tents (30ft wide x 100ft long) for transient personnel, storage, or miscellaneous purposes. These big tents occupy a total area of 31,320 total square feet al.l these tents require 626,400 BTUs per hour for their cooling. There are 137 large tents (30ft wide x 100ft long) used for training or large briefs. The total covered area of these big tents equals 438,400 total square feet, resulting in 8,768,000 BTUs per hour. There are 100 larger CHUs (15ft x 50ft) for higher ranking officials or their offices. Total covered area of these big CHUs equals 75,000 square feet resulting in 1,500,000 BTUs per hour. There are two types of offices. The smaller ones have a standard size of 30ft x 10ft and the bigger ones have a standard size of 495ft x 40ft. There are 96 smaller offices and 15 bigger offices. The total area equals 48,600 square feet, and the corresponding consumption equals 972,000 BTUs per hour. There are 60 miscellaneous tents and buildings on the southern side of the camp, requiring approximately 2 million BTUs per hour. There are around 110 various large buildings, latrines and restroom facilities around the base. There are flight-line buildings covering approximately 47,095 square feet.

The first drawback we observed with this approach was that the load could vary depending upon the insulation of each building, season of the year, number of accessories in each building, utilization hours of various equipment, and number of personnel at any particular time of the year. Consequently, military planning is carried out to cater for the peak season/hours consumption; however, electric consumption based on the intractable model did not make sense for an accurate analysis.

The second drawback was the selection of a particular generator for meeting electricity requirements to calculate operation and maintenance cost. There are a number of guiding principles regarding selection of a particular generator based on the size and electricity consumption of a particular base. Moreover, available generators for installation on FOBs include Deployable Power Generation and Distribution Systems (DPGDS), Mobile Electric Power/Prime Power, Multi-unit 4.5 MW Electro Motive Division (EMD) plants and Tactical Quiet Generators (TQG) (Noblis Report, 2010). Each generator has its own capabilities and limitations based on its utility. One may be more fuel economical, but may not be suitable for a certain utility. For example, it may be difficult to transport or relocate. The selection of any specific diesel generator for calculations of our operation and maintenance costs for diesel generators was not a true representation of all DoD-wide costs, and outside the scope of this study.

Finally, we concluded that using LCOE is most suitable for the purpose of our analysis due to the following reasons:

1. Takes into account all factors depicted in our model
2. Gives unit cost for all sources of electricity generation
3. All assumptions are equally applicable to all sources of generation
4. Data was from very reliable sources and based on deep research
5. Updated regularly based on current trends in technology pertaining to all sources of generations
6. Could be used to make informed estimations and forecasting due regular updates

LCOE is the constant unit cost (per kWh or MWh) of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life. There are multiple ways to calculate LCOE, depending on the level of financial detail.

Assumptions can have significant impact on the resulting LCOE, so consistent assumptions across technologies are important. It is, therefore, important to select assumptions consistently across the sources and with the agreement of all relevant stake holders. Some of the key assumptions are:

1. Capacity factor (performance)
2. Weighted Cost of capital (WACC)
3. Capital cost

The concept of LCOE is illustrated in Figure 2. The left-hand side of the vertical-axis mark the total cost over the period of time depicted across the horizontal axis. Resulting LCOE is graduated on right-hand side of the vertical axis.

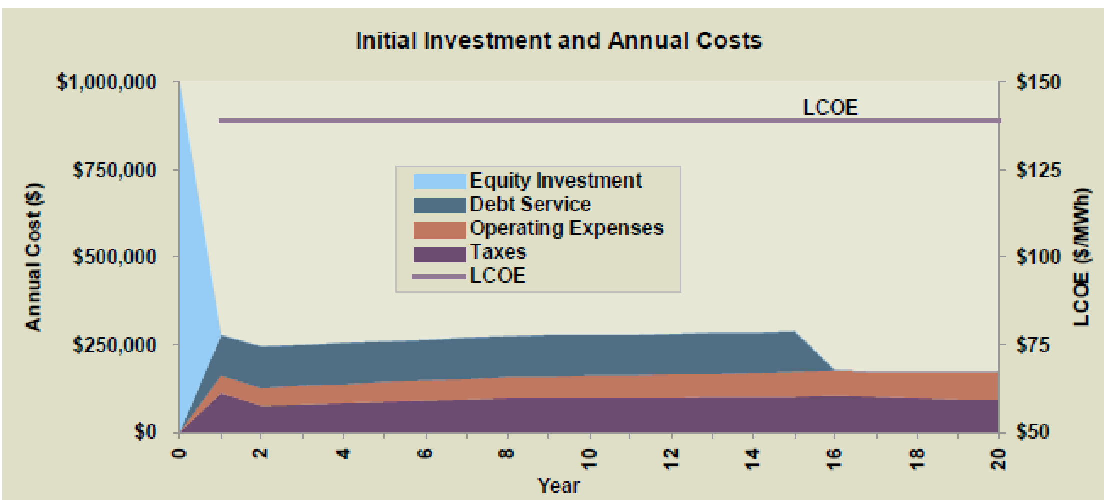

Figure 2. Concept of Levelized Cost of Electricity (From Black & Veatch, 2010)

The major reason for using LCOE for our analysis is the fact that LCOE is very useful in comparing technologies with different operating characteristics. Competing renewable technologies are labeled on the vertical axis, while corresponding LCOE is on the horizontal axis (Figure 3).

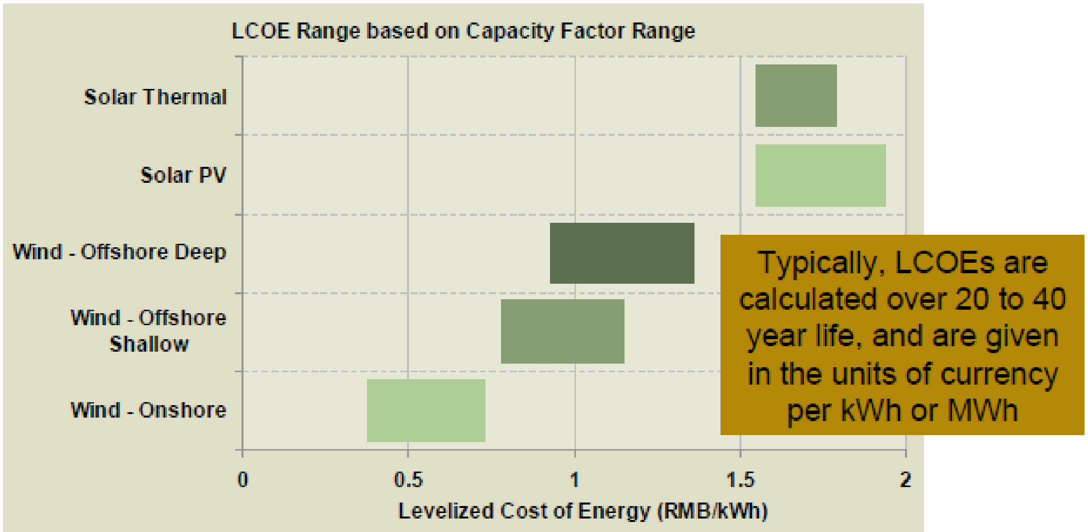

Figure 3. LCOE Range Based on Capacity Factor Range (From Black & Veatch, 2010)

It can, therefore, be concluded that the best reliable source is using LCOE for cost comparison across competing renewable technologies. Detailed comparative analysis of LCOE by source will be carried out in Chapter IV.

IV. ANALYSIS

The basic formula to determine LCOE starts with equating costs and revenues. This can be represented in the following simple formula.

Cost structure = electricity output * cost of electricity

Therefore, the cost of the electricity of your LCOE can be defined as:

LCOE = (Cost Structure / Electricity Output)

Renewable energy sources including solar PV cells do not provide a one-size-fits-all solution. Renewable resources are distributed around the globe and energy-generation patterns vary worldwide especially in case of solar PV. Therefore, a simple formula expressed above becomes very complex when taking into account project costs, annual operating costs, discount rates, tax credits, depreciations, number of years for the system, up time (time for which system is generating electricity), interest payments, loan structure, annual degradation, and capacity factor (performance/efficiency). To have synchronization and consistency between numbers, we have selected the LCOE data published by Transparent Cost Database website for NREL's information regarding vehicles, biofuels, and electricity generation (U.S. DoE, 2012). We analyzed the cost trends over a period of time for various renewable energy resources published in department of energy annual outlook reports of 2011 and 2012 for plants entering in service in 2016 and 2017, respectively.

Figure 4 displays a simple LCOE calculator.

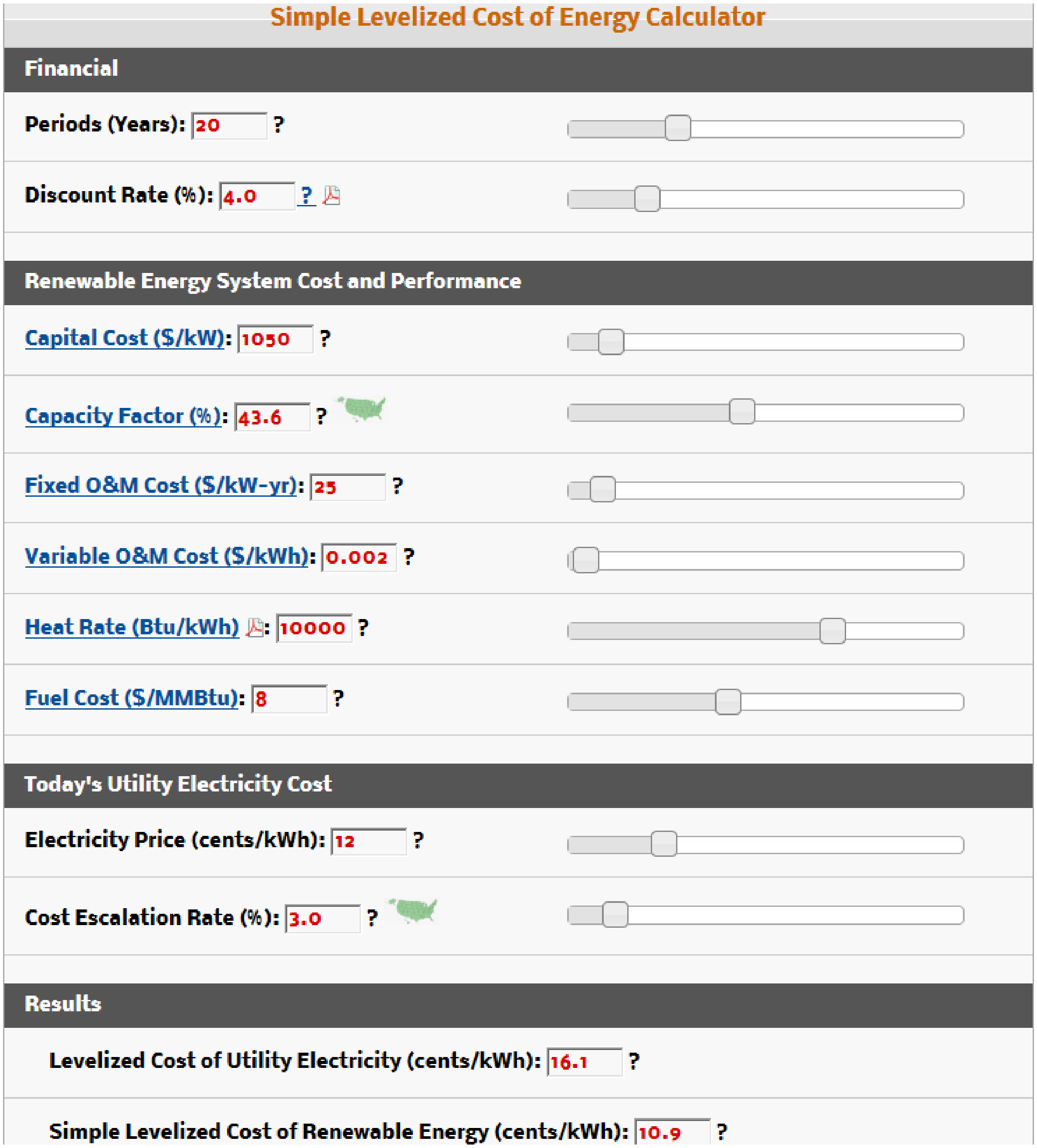

Figure 4. Simple LCOE Calculator (From NREL, 2012)

A. CURRENT LCOE

Tables 1 and 2 list the estimated cost of electricity, by source, for plants entering service in 2016 and 2017.

Table 1. Estimated Levelized Cost of New Generation Resources, 2016.

Plant Type	Capacity Factor (%)	U.S. Average Levelized Costs (2009 $/megawatthour) for Plants Entering Service in 2016				
		Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Conventional Coal	85	65.3	3.9	24.3	1.2	94.8
Advanced Coal	85	74.6	7.9	25.7	1.2	109.4
Advanced Coal with CCS	85	92.7	9.2	33.1	1.2	136.2
Natural Gas-fired						
Conventional Combined Cycle	87	17.5	1.9	45.6	1.2	66.1
Advanced Combined Cycle	87	17.9	1.9	42.1	1.2	63.1
Advanced CC with CCS	87	34.6	3.9	49.6	1.2	89.3
Conventional Combustion Turbine	30	45.8	3.7	71.5	3.5	124.5
Advanced Combustion Turbine	30	31.6	5.5	62.9	3.5	103.5
Advanced Nuclear	90	90.1	11.1	11.7	1.0	113.9
Wind	34	83.9	9.6	0.0	3.5	97.0
Wind – Offshore	34	209.3	28.1	0.0	5.9	243.2
Solar PV[1]	25	194.6	12.1	0.0	4.0	210.7
Solar Thermal	18	259.4	46.6	0.0	5.8	311.8
Geothermal	92	79.3	11.9	9.5	1.0	101.7
Biomass	83	55.3	13.7	42.3	1.3	112.5
Hydro	52	74.5	3.8	6.3	1.9	86.4

[1] Costs are expressed in terms of net AC power available to the grid for the installed capacity.

Source: Energy Information Administration, Annual Energy Outlook 2011, December

Table 1. LCOE by Renewable Sources 2011 (From EIA, 2011)

Plant Type	Capacity Factor (%)	U.S. Average Levelized Costs (2010 $/megawatthour) for Plants Entering Service in 2017				
		Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Dispatchable Technologies						
Conventional Coal	85	64.9	4.0	27.5	1.2	97.7
Advanced Coal	85	74.1	6.6	29.1	1.2	110.9
Advanced Coal with CCS	85	91.8	9.3	36.4	1.2	138.8
Natural Gas-fired						
Conventional Combined Cycle	87	17.2	1.9	45.8	1.2	66.1
Advanced Combined Cycle	87	17.5	1.9	42.4	1.2	63.1
Advanced CC with CCS	87	34.3	4.0	50.6	1.2	90.1
Conventional Combustion Turbine	30	45.3	2.7	76.4	3.6	127.9
Advanced Combustion Turbine	30	31.0	2.6	64.7	3.6	101.8
Advanced Nuclear	90	87.5	11.3	11.6	1.1	111.4
Geothermal	91	75.1	11.9	9.6	1.5	98.2
Biomass	83	56.0	13.8	44.3	1.3	115.4
Non-Dispatchable Technologies						
Wind	33	82.5	9.8	0.0	3.8	96.0
Solar PV[1]	25	140.7	7.7	0.0	4.3	152.7
Solar Thermal	20	195.6	40.1	0.0	6.3	242.0
Hydro[2]	53	76.9	4.0	6.0	2.1	88.9

Table 2. LCOE by Renewable Sources 2011 (From U.S. EIA, 2012)

As we have previously discussed LCOE is a convenient measure of the overall competiveness of different generating technologies. LCOE represents the present value of the total cost of building and operating a generating plant over a certain period of time. It is very clear from the numbers in total system levelized cost column of Tables 1 and 2 that solar-produced electricity is much more costly, as compared to gas fired plants.

However, we shall not take these numbers as binding to make any decisions due to the following reasons:

1. The availability of various incentives including state or federal tax credits can also impact the calculation of Levelized cost. The values shown in the tables below do not incorporate any such incentives. Although these incentives are time based and are meant to encourage development of certain technologies, yet they have social benefit equivalent to these incentives. PV solar cells have an advantage over diesel generators in this respect and may bring the cost of LCOE for solar generated electricity further down, if calculated.
2. Similarly, levelized capital costs of coal-fired plants without Carbon Control and Sequestration would have been less in case of a 3-percentage point increase in the cost of capital was not added in the weighted average cost of capital (WACC). However, this additional tax is imposed to compensate the negative externality caused by the technology. Imposition of this tax has a social value and can be justified.
3. The costs shown are U.S. national averages. There may be significant variation in costs of labor, fuel or energy resources. The regional variation in LCOE of PV cells entering in service by 2017 varies between $119.0 and $238.8 (2010 $/MW hour). This variation will be favorable for regions with more Sunny days as compared to regions with less Sunny days (U.S. EIA, 2012).
4. The other related capacity factor (performance) depends on both the existing capacity mix and load characteristics in a region. The capacity factor for PV cell is taken as 25 percent while it is taken as 87 percent for gas fired technologies. Currently, PV cells have efficiency concerns at industrial levels; however, the current rapid growth in PV technology is very promising. 43.5 percent efficiency has already been achieved for compound multi-junction concentrated PV (CPV) (Irena, 2012) and is only a matter of time when it will become competitive. It is a matter of separate research that what will be the actual effect of the incremental increase in capacity factor expected for PV cells. However, one thing that can be assumed with a high degree of confidence is that with a partial increase in the capacity factor of PV cell will result in reduced LCOE and make solar cells more competitive against other matured technologies including Diesel Generation.
5. As per Swanson's law, solar cell prices fall 20 percent for every doubling of industry capacity (Carr, 2012). This observation is very similar to the famous Moore's Law which states that the number of transistors on integrated circuits doubles approximately every two years. This trend has continued for more than half a century from 1965 to 2005. In fact Moore's law has been equally applicable

to processing speed, memory capacity, sensors and even the number and size of pixels in digital cameras. There has been a rapid growth in production of PV cells in the past and is trending upward with each passing year. Over the past five years, annual installations of photovoltaic (PV) systems have grown 60 percent per year globally and 53 percent per year in the United States. In fact, in 2011 alone, the United States installed roughly 2 GW of the 21 GW of PV installed globally, which was a 109 percent increase over 2010 (U.S. DoE, 2012) Specifically, bottom-up analysis for systems quoted in Q4 2011 (and installed in 2012) yields installed prices of $4.39/W for 5.1-kW residential systems, $3.43/W for 221-kW commercial rooftop systems, and $2.79/W for 191.5-MW fixed-tilt utility-scale systems, corresponding to a 25 percent–29 percent year-over-year reduction compared to Q4 2010 benchmarks (U.S. DoE, 2012). If this growth trend continues and prices continue to decrease as projected, PV cells will become competitive in 2018.

6. The difference in LCOE of solar PV for plants entering into service by 2016 and 2017 depicted by the Energy outlook 2010 and energy outlook 2011 is 210.7$ /MWh (2009 $) – 152.7 $ / MWh (2009 $) = 27.3 percent decrease (not adjusted for inflation). This data also suggests that with current forecasts LCOE PV cells will become comparable with diesel generation by 2018.

C. OTHER FACTORS

Cost is not the only factor that determines the suitability of the installation of PV cells on enduring DoD installations. The other factors that also need to be considered include extraction, emissions, transmission, health, peak loads, and seasonal, as well as day/night time variability, in electricity generation. The cost will include the price of batteries if storage is utilized to cater to variability.

Solar Irradiance is a major factor that directly affects the competitiveness of solar cells with other sources of electricity generation. Solar Irradiance measures how much solar power is available at a certain location. Irradiance varies throughout the year depending, on the seasons, and it also varies throughout the day, depending on the position of the Sun in the sky, and the weather. Solar Irradiance is normally expressed as Solar Insolation, which is a measure of Solar Irradiance over the period of a single day. Figure 5 displays average irradiance per month for the city of Saba as Salim, Kuwait, and San Jose, California. Saba as Salim has better irradiance throughout the year, except for the months of April and May. The Middle East contains better overall irradiance as compared to the United States.

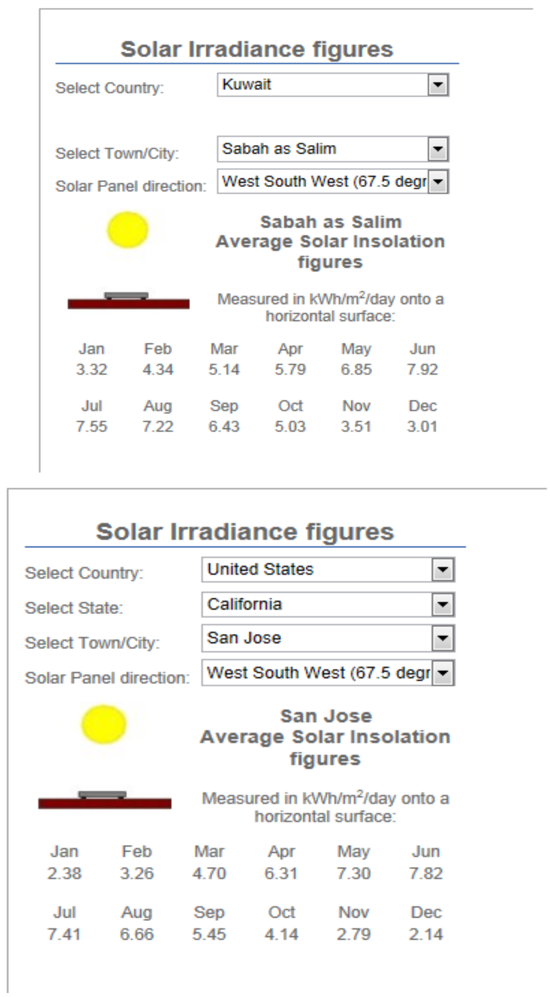

Figure 5. Solar Irradiance (From Boxwell, 2013)

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V. CONCLUSION

DoD have forward operating bases (FOB) around the world. The cost effective sustainability of these FOBs has attained much focus because of budget constraints. FOB sustainment seems to remain a relevant issue in foreseeable future. There are many avenues to improve the sustainability (i.e., logistic support costs, efficient supply chain management, decreasing fuel dependence, fast mobility, and reducing casualties). Reliance on fuel can be reduced, and hence, conveys movement by increasing use of renewable energy at FOBs. In the words of Major General Richard Zilmer, "Without renewable power, U.S. forces will remain unnecessarily exposed and will continue to accrue preventable… serious and grave casualties." (DoD, 2010).

Similarly Dr. Ash Carter, the Under Secretary of Defense for Acquisition, Technology, and Logistics, commented

> protecting large fuel convoys imposes a huge burden on combat forces" and "reducing the fuel demand would move the department more towards an efficient force structure by enabling more combat forces supported by fewer logistics assets, reducing operating costs, and mitigating budget effects caused by fuel price volatility. (Noblis, 2010).

The primary goal of this research study was to carry out feasibility study for installation of using PV solar panels at DoD enduring installations for electricity generation. Key findings of our research include:

1. Levelized Cost of Electricity (LCOE) for solar PV cell is higher than gas fired plants.
2. PV is currently only competitive with residential tariffs in regions with good solar resources, low PV system costs, and high residential tariffs.
3. The prospects for continued cost reductions for PV cell technology are very good. Learning curve for gas fired plants is flat due technology maturity while PV cell technology has a steep learning curve. Only expected price reduction in gas fired plants correlates with reduced price of the gas. PV cell has potential to reduce costs due technology maturity and increasing efficiencies.
4. If the current trend of PV cell growth and reduction in associated cost continues, we expect PV cell electricity will become competitive by 2020.

5. There was considerable difference between costs based on the difference in underlying data and associated assumptions made during cost calculation. Our attempt was to acquire data from an authorized source (DOE), which contains consistent assumptions over the years.
6. The DoD goal is to produce or procure 25 percent renewable energy from its total facilities of energy consumption.
7. There are many problems with electricity generation from Diesel generators at FOB. The significant one being that power generation far exceeds demand at most FOBs. At Camp Leatherneck, the 5 MW of demand is met by 19 MW of capacity, with 196 generators running at 30 percent capacity and consuming 15,431 gallons of fuel per day (Noblis, 2010). Moreover, the fully burdened cost of fuel vary from $16.25 to $ 34.31 per gallon (Noblis, 2010). LCOE by sources does not take into account this additional cost element. The exact relation has not been established yet it will definitely cause LCOE for diesel generation of electricity. At the same time, security costs of PV cells installations have not yet been catered for. This will also add some premium to the cost of electricity generated by PV cells.

RECOMMENDATIONS

Following are recommendations for further research.

1. Strategic Environmental Research and Development Program for addressing the sustainability issues at FOBs is already in progress. Complete Cost benefit analysis may be carried out to shift to solar energy
2. Data from DoD installation using PV cells like Nellis Air Force base may be obtained and further analyzed with respect to its cost effectiveness. Year wise cost data may be used to forecast future costs.

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